Platform requirements for offline and real-time simulations

Inter OPERA
Enabling multi-vendor HVDC grids

PUBLIC

ABOUT INTEROPERA:

The InterOPERA project will define technical frameworks and standards for electricity transmission and accelerate the integration of renewable energy. Ensuring that HVDC systems, HVDC transmission systems or HVDC components from different suppliers can work together – making them "interoperable"- is a top priority to accelerate Europe's energy transition.

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AUTHORS:
Aleksandra LEKIĆ, TU Delft
Alexandra BONNET, RTE
Benoit DE FOUCAUD, RTE
Farzad DEHGHAN MARVASTI, TU Delft
Marjan POPOV, TU Delft
Remko KOORNNEEF, TU Delft
Reza BAKHSHI-JAFARABADI, TU Delft

REVIEWERS:
Alexander NEUFELD, Energinet
Emmanuel AMANKWAH, GE Vernova
Fainan HASSAN, GE Vernova
Holger SCHULDT, Siemens Energy
Nemanja KRAJISNIK, Siemens Energy
Robert DIMITROVSKI, TenneT
Sebastian HARANT, Siemens Energy
Sébastien DENNETIERE, RTE

OTHER ACTIVE CONTRIBUTORS:
Andreas SAÇIAK, 50Hertz
Bhadra WARRIER, GE Vernova
Carlo DEGLI ESPOTI, T&D Europe
César MARTIN, RTE
Christian WIKSTROM, Hitachi Energy
Christoph GRINGMUTH, GE Vernova
Gustavo Figueiredo GONTIJO, Ørsted
Hamidreza MIRTAHERI, Vestas
Hélène CLEMOT, RTE
João Pedro AYRES PEREIRA DA CUNHA RAMOS, Vestas
Julien POUGET, RTE

Kanakesh VATTA KKUNI, Siemens Gamesa
Klaus VENNEMANN, Amprion
Nico KLÖTZL, TenneT
Samuel DE MARIA, TERNA
Sébastien SILVANT, SuperGrid Institute
Xiu LIU, GE Vernova
Yatin PRAKASH BISNE, Siemens Gamesa
Yicheng LIAO, Energinet

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Table of Contents

1. Executive summary

To perform interaction studies efficiently with complex grids, such as multi-vendor multi-terminal HVDC grids connected to offshore wind parks, the system integrator shall put in place the relevant hardware, software and organizational solutions.

In case of real-time platforms, the system integrator shall even consider some specific constraints on the facility for a smooth installation and use of the equipment.

The purpose of this document is to describe the minimum requirements that shall be fulfilled by the system integrator to prepare for interaction studies. These requirements are referenced as "LAB-OFF" (for offline), "LAB-RT" (for real-time) or "LAB-COM" (for both).

It also describes some minimum requirements to be fulfilled by the ElectroMagnetic Transients (EMT) tools for these tools to be selectable by the system integrator. These requirements are referenced as "EMT-OFF" (for offline), "EMT-RT" (for real-time) or "EMT-COM" (for both).

2. Definitions

In this document:

- "HIL" – Hardware-in-the-Loop terminology is used to describe the hardware with its associated software, delivered by the manufacturer, to be used by the system integrator to perform real-time simulations, when the hardware is the same as the one that is installed on site for commercial projects (or the state-of-the-art one in the context of InterOPERA).
- "SIL" – Software-in-the-Loop terminology is used to describe the software delivered by the manufacturer, to be used by the system integrator to perform real-time simulations (in InterOPERA, SIL is **not** used for offline models based on real-code). In case of SIL, there are two main options:
  - The software is running on hardware provided by the vendor, but this hardware cannot be considered as HIL. In that case, the same requirements as for HIL shall be considered to host this hardware and to interface it with the real-time simulator.
  - The software is running on a hardware provided by the system integrator (most likely the real-time simulator itself). In that case, a specific requirement has been defined, and some requirements, related to hardware specific constraints, might not be applicable. This is left on purpose to the discretion of the system integrator, depending on the situation.
- "real-time platforms" is used to describe any software or firmware processing platform running in real-time. In InterOPERA, it can be used for HIL as well as SIL or a combination of both.
- "real-time simulator" or "real-time simulation tool" is used to describe any simulator or simulation tool, which performs simulations in real-time. It can be interfaced with HIL as well as SIL, running on an external hardware, or running on the simulator itself.
- "real-time simulation" is used to describe any simulation running in real-time. The simulation is obtained thanks to the real-time simulator, interfaced with HIL as well as SIL.

3. Platform requirements for offline simulations

3.1 Introduction

LAB-OFF 1.

The system integrator in charge of the interactions studies defined in [1] shall have an offline platform which enables to perform easily complete and complex power system studies. In particular, the platform must be able to execute time-domain simulations of electromagnetic and electromechanical transients for control and protection systems, covering phenomena over the frequency range from 0.2 Hz to 2500 Hz.

LAB-OFF 2.

Optionally, the system integrator shall select an offline platform enabling frequency-scan for the frequency-domain impedance representation if frequency-domain tests are part of the tests to be performed.

LAB-OFF 3.

It is the responsibility of the system integrator to select and buy the relevant hardware and software to be able to perform all the studies in a suitable amount of time.

Regarding the software, the system integrator shall be equipped with at least one offline EMT simulation tool, based on the requirements defined in 3.2.

Information

Each EMT software developer defines the minimum hardware and software requirements to support its EMT tool and may also define additional software that shall be installed complementary to its EMT tool.

However, to perform efficiently complex simulations, such as the ones for InterOPERA, it might be necessary to use more powerful computers than the minimum ones.

3.2 Offline EMT software requirements

3.2.1 Modelling and simulation capability

EMT-OFF 1.

The EMT software must be able to solve any scenario defined in [1], and at least the following types of electrical scenarios:

- Faults and the resulting circuit breakers' trips
- Switching events linked to the re-configuration of the grid (e.g. circuit breaker opening and closing)
- Equipment energisation
- Change of control input
- Lightning events[1]

EMT-OFF 2.

The EMT software must include comprehensive models for all the relevant electrical and mechanical components which can be found in the transmission grid, reflecting all phenomena to be observed for the above-mentioned scenarios, in the frequency range from 0.2 Hz to 2500 Hz and shall be able to handle the associated control and protection system actions. It shall ensure sufficient accuracy.

Information

In Offline EMT Modelling References section, a list of IEC, CIGRE and IEEE references gives ideas regarding typical phenomena which can be modelled and some modelling method examples. These publications are not limitative. Namely, other well documented and well proven modelling methods can be used in the EMT tools.

Example

For instance, the electrical models could include:

- Detailed, accurate models of power lines and cables, including travelling wave and frequency dependency
- Comprehensive models of transformers including magnetic core saturation and hysteresis
- HVDC converter models

Additionally, the EMT software might need to include for some projects:

- Electrical machine models
- IBR models
- FACTS models
- An extensive library of control devices and relay models

EMT-OFF 3.

[1] It is worth pointing out that lightning events are listed here, to be more generic and consider also design studies but are not described in D1.3.

The EMT tool developer shall document the computing performance of its tool, based on clear examples including:

- A description of the model: what is the number of electrical nodes, the size of the matrix, which type of components and phenomena are included, are there non-linearities, control loop, DLLs, etc.
- A description of the simulation: what is the purpose of the simulation, what is the solving method, what is the time step, does it include the initialization or does it start from a snapshot, etc.
- A description of the hardware used
- A description of the resulting computing time

Information

This is necessary for the system integrator to select and purchase the most relevant hardware and software, depending on the number of simulations to be performed and their complexity.

EMT-OFF 4.

The models from the software library must be clearly documented for the system integrator to check that the models which will be used fit with EMT modelling standards and with the purpose of the studies to be performed.

3.2.2 Interfaces

EMT-OFF 5.

The EMT software must be able to integrate models which are delivered in the form of a DLL defined according to the IEEE/CIGRE DLL [2] .

Information

The DLL allows vendors to share their EMT models as black box. This type of tool- and compiler[2]-independent DLL will be decisive for multi-vendors' project. For this reason, this provision is defined in [3] and the offline platform cannot miss the possibility to run DLLs using this methodology.

EMT-OFF 6.

It is recommended to have the possibility to import and export models in line with:

- IEC 61970 Energy Management system application program interface (EMS-API) - Part 302: Common Information Model (CIM) dynamics [4]

[2] Except for few options to be listed. Indeed, full independency with the compiler can't be achieved. For example, a DLL compiled with 64 bit-compilers cannot be used when 32 bit-words are required.

- IEC 61970 Energy Management system application program interface (EMS-API) - part 457: Dynamics profile [5]

Information

The IEEE/CIGRE DLL methodology [2], mentioned in the previous requirement, is mainly expected for the control and protection. Consequently, this solution, even if promising, does not solve all the issues faced by the users. Indeed, when a model must be integrated in a different tool, a lot of manual work is still necessary to recreate the electrical circuit in this new tool.

Thanks to the IEC 61970 standards mentioned in this requirement, commonly known as CIM, the target is to overcome this limitation and to simplify model exchange and integration in commercial software. To reach this goal, these standards define standard interfaces and models that can be used to exchange dynamic model information. This requirement is applicable to the EMT tool developers. When writing this document, no extra work from the vendors is expected to prepare a model based on CIM.

LAB-OFF 4.

The system integrator shall evaluate if other interfaces are necessary for a given project and select the EMT tool accordingly.

Information

The requirements defined in [3] are applied and hence, no additional interface is necessary. Besides, it is recommended to use those requirements for future commercial projects, so that no additional interface would be necessary for interaction studies related to multi-vendor multi-terminal HVDC grids connected to OWF.

However, it might happen that interaction studies have to be performed with the existing components of the AC onshore grid, whose models have been previously provided, based on other types of interfaces. In that case, it might be necessary to select an EMT tool which includes functions for interfacing with other types of data (e.g. data related to the Functional Mock-up Interface, DLL generated by Simulink, etc.).

3.2.3 Practical aspect

EMT-OFF 7.

The software shall have the possibility to copy any model – potentially composed by multiple modules – in one file, and to paste it in another file containing another model.

3.2.4 Tests parallelisation

EMT-OFF 8.

It shall be possible to automatise the computation of different tests in parallel – for different processes - with the EMT software.

Justification

This is especially crucial when the number of cases to be tested is high, in order to reduce the calculation time and, thus, the time needed to perform all the studies.

Information

This requirement does not presume of the solution. What is important, from a user perspective, is the ability of the EMT tool to automatically share the computation load on different processes, when one list of tests is prepared thanks to EMT-COM 1.

3.2.5 Parallelisation of one simulation

EMT-OFF 9.

It is highly recommended to have a simulation platform which can perform parallelisation of a given complex simulation, i.e. which can use multiple processes to compute one given simulation.

For this simulation's parallelisation, it is recommended to have the possibility:

- To select different time steps for the different parts that are simulated in parallel
- To use different solvers for the different parts that are simulated in parallel
- To start the simulations of the different parts at different times

Justification

The importance of parallelisation in EMT simulations is crucial, especially for the validation of complex models. To ensure the accuracy and reliability of a model, it is essential to perform numerous simulations, adjusting both the parameters and the model itself to exactly meet expectations. Given the complexity and precision required by these simulations, each execution can last several hours on a single processor. Once the model is validated, it becomes possible to explore different scenarios and perform parametric simulations.

Parallelisation offers an effective solution to this problem. By distributing the calculations across multiple processors simultaneously, the total time needed for simulations can be significantly reduced. This not only shortens the validation but also allows for a more thorough investigation of the model's behaviors in a reduced time frame.

For the design engineer, this time saving presents a major advantage. Reducing the time needed to validate a model means that progress on the project can be made quicker, with adjustments and improvements being made more agilely. Moreover, from a project-wide perspective, the parallelisation of EMT simulations reduces the number of man-days required, thus, enabling more efficient resource management and a reduction in associated costs.

The three possibilities mentioned for simulations' parallelisation are aiming at reducing even more the necessary computing time.

4. Platform requirements for real-time simulations

4.1 Platform facility requirements

LAB-RT 1.

The facility shall provide at least a 230V AC power supply for the equipment installed by the manufacturer, and optionally, it provides a DC power supply as per vendor's need.

Information

The deadline for the manufacturer to provide the AC (and optional DC power consumption) shall be in line with the necessary time for the system integrator to adapt its facility. In InterOPERA, a one-year period is defined.

LAB-RT 2.

The facility needs to guarantee a maximum constant ambient temperature of 25°C and a minimal constant ambient temperature of 15°C; and a relative humidity below 75%

Information

By default, unless otherwise stated by the vendor, the heat dissipation coming from the vendor's hardware used for the sizing of the air handling unit is deemed equal to the electrical power consumption.[3]

This requirement is adapted to InterOPERA and could be strengthened depending on the duration the cubicles will be installed in the lab. For example, one could think at the dust.

LAB-RT 3.

The lab shall coordinate with the supplier for the synchronization.

Information

There are usually three different options which can be defined:

- The supplier is fully responsible for the synchronization system, including the provision and installation of a Global Navigation Satellite System antenna

[3] It is reminded that the heat dissipation coming from the vendor's hardware is not the only input to be considered for the design of the air conditioning.

- The Global Navigation Satellite System antenna is in the scope of the system integrator, and the supplier only provides the master clock
- The system integrator provides the master clock

LAB-RT 4.

Easy delivery and transport of the cubicles up the platform shall be considered for cubicles installation and delivery. In particular, the path between the unloading area and the platform shall:

- Be short
- Have at least a minimum width compatible with EU pallet transportation
- Have at least a minimum path height of 2m50
- Be without step.

Information

The transportation of the vendor hardware is usually in the scope of the supplier, as well as the unloading of the hardware from the truck – with adapted tools. Therefore, for the vendor to evaluate the need for adapted tools, additional information might have to be exchanged between the vendor and the lab. For example, depending on the unloading area configuration, a truck equipped with tail gate might be highly recommended.

LAB-RT 5.

The facility shall support a minimum weight per area to be in line with vendor's cubicles weight and shall consider a minimal height allowing easy installation of the cubicles as well as optimal air flow.

LAB-RT 6.

If requested by the manufacturer, it shall be possible to fix solidly the cubicles to the ground.

LAB-RT 7.

Dedicated earthing terminals, fulfilling the requirements from the vendors, shall be provided.

Justification

This is for the earthing of equipment delivered by the vendors.

LAB-RT 8.

The system integrator is responsible for providing cable's corridor for the cables between cubicles, power supply, RTS.

The entry side for the cables shall be provided to the vendor in due time.

Example

The corridor consists of a cable's tray, space under the false floor.

LAB-RT 9.

The system integrator shall provide in due time a layout of the facility showing the general arrangement of the facility, including at least the location of the cubicles, of the RTS, of the HMI, of the power supply (i.e. location of the connecting terminals), of the remote access connection point, of the synchronization system.

Justification

This is for the vendor to evaluate the required cable lengths.

LAB-RT 10.

The system integrator shall coordinate with the vendor to define each interface type (for example: type of optical fibre and of its connector, type of the socket for the power supply, etc.).

LAB-RT 11.

Unless agreed differently between corresponding vendor and system integrator, it is recommended to use the following table as a rough reference to evaluate the size of the platform to host all the cubicles provided as HIL:

Type of vendor	Approximate number of cubicles
HVDC converter station	10/20 per bipole
PPM	2 per wind farm, fully aggregated
DC Grid controller	2
DC switching station	2

With a minimum width compliant with local EHS requirements.

Information

This table is based on InterOPERA experience. It can evolve in the future depending on the features to be included in the cubicles (ex: additional hardware for DBS, detailed wind turbines, etc.).

LAB-RT 12.

The platform shall be equipped to ensure the absence of rodents.

LAB-RT 13.

General arrangement of the platform shall ensure that the maximal lengths for connection between [the cubicles and the RTS], and between [the cubicles and the workstations] are not exceeding the maximal supported length required for a good performance.

4.2 Accessibility of the platform

In addition to the requirements defined in section 5.5 of this document, the following requirements apply:

LAB-RT 14.

Access to the platform shall be secured so that only authorized people can access to the cubicles and vendors' workstations.

LAB-RT 15.

The system integrator is responsible for ensuring that people with authorized access to the platform have no possibility to actively try to access to the IP of vendors.

LAB-RT 16.

Access to the platform is subjected to an agreement of confidentiality between the system integrator and the manufacturers.

Information

Further information can be found in the deliverables published by InterOPERA WP4 ([6]) and WP5.

LAB-RT 17.

It is strictly forbidden for everybody within the project to do any kind of reverse engineering on the hardware and software delivered by the vendors of the project.

LAB-RT 18.

The facility shall target the following confidentiality rules between vendors during co-activity phases:

- For auditive confidentiality, a conversation at 60dB(A), measured at 1m, of one vendor shall not be understandable by another vendor
- For visual confidentiality, a vendor, sitting or standing in its area, shall not distinctly see the content of the cubicles of another vendor

If requested by the manufacturer, the possibility of avoiding co-activity shall be organized with the system integrator and the manufacturer.

LAB-RT 19.

In any case, the facility shall target the following confidentiality rules with regards to third-party people circulating around the platform:

- For auditive confidentiality, a conversation at 60dB(A), measured at 1m, in the platform shall not be understandable outside of the platform

- For visual confidentiality, during the installation phase, when the cubicles are open, it shall not be possible to distinctly see the content of the cubicles

4.3 Remote access

LAB-RT 20.

The system integrator shall provide an Internet access point for the vendor to have the possibility to access remotely to its system.

By default, the Internet access point is secured by the manufacturer. However, there can be a common agreement between the manufacturer and the system integrator to jointly secure this Internet access point.

LAB-RT 21.

It is the responsibility of the system integrator to install the Internet connection point close enough to the vendor's system, so that from the vendor's side, no additional repeaters are necessary due to cable length restrictions.

LAB-RT 22.

The system integrator can optionally provide remote access to the RTS.

4.4 Requirements for the Real-Time Simulator

4.4.1 Introduction

LAB-RT 23.

The system integrator in charge of the interactions tests defined in [1] shall have a real-time platform which is able to perform complete and complex power system studies. In particular, it must be able to execute, in real-time, simulations of electromagnetic, electromechanical transients covering phenomena lasting from microseconds to hours. Additionally, even if one advantage of the real-time simulator is the possibility to interface it with the control and protection system provided by the station's vendor, it shall also be possible to run some generic control and protection systems on the simulator itself[4].

[4] This is to perform tests with a circuit including generic models, for example for single-vendor tests or for multi-vendor interaction tests if one or several vendors have not delivered their system yet.

LAB-RT 24.

The system integrator shall be equipped with at least one real-time EMT simulator, considering the requirements defined in section 4.4 of this document.

LAB-RT 25.

The number of licensed cores, the number of IO interfaces of the real-time simulator and the provision of additional boards and cards, shall be adapted to the solution provided by the real-time system's manufacturer, including the manufacturers (or hardware) IO requirements and to the type of studies to be performed.

LAB-RT 26.

The host PC connected to the simulator shall comply with minimum requirements defined by the simulation system supplier.

In addition, it is the responsibility of the system integrator to determine if higher requirements for the host PC connected to the simulator or if additional computers[5] are deemed necessary to be able to perform all the studies in the allocated amount of time.

4.4.2 Real-time simulation tool

EMT-RT 1.

The simulator must be able to solve in real-time any scenario defined in [1] and to solve the following type of electrical scenarios:

- Faults and the resulting circuit breakers' trips
- Switching events linked to the re-configuration of the grid (e.g. circuit breaker opening and closing)
- Equipment energisation
- Change of control input

EMT-RT 2.

The simulator to be chosen for the tests must include comprehensive models for all the relevant electrical and mechanical components which can be found in the transmission grid, reflecting all phenomena to be observed for the above-mentioned scenarios, and shall be able to handle the associated control and protection system[6].

[5] Additional computers could be useful, for example, to prepare the reports, to organise the files obtained from the simulations, to prepare for future tests, etc.

[6] This is for the control and protection system that could be running on the RTS, if needed, for example, to perform some tests with generic models. In addition, there are other solutions described in separate requirements: interfacing with the control and protection system provided as HIL, and providing a solution for computing SIL.

The modeling shall assure the accuracy of the simulations, while considering real-time limited computing time.

Information

It is recommended to use CIGRE or IEEE modelling publications as a reference, according to the preferences. If necessary, the choice of the standard should be determined and agreed ahead of the project.

Example

For example, the electrical models could include:

- Detailed, sufficiently accurate models of power lines and cables
- Comprehensive models of transformers including magnetic core saturation and hysteresis[7]
- HVDC converter models

Additionally, the simulator might also include:

- Electrical machine models
- IBR models
- FACTS models
- An extensive library of control devices and relay models

EMT-RT 3.

The simulator shall include a solution to enable SIL or a combination of HIL and SIL through:

- The use of black-box models delivered by the vendors
- Their integration into a real-time simulation by the system integrator.

Information

The solution can consist of a combination of a software library, for vendors to prepare compiled files, and additional simulator hardware for the execution of these compiled files.

This requirement lays down the basis for SIL, or a mix of SIL and HIL interaction tests.

However, it is worth pointing out that there is currently no common software library for the different real-time simulator brands and this could be a limitation for a system integrator to perform multi-vendor interaction tests.

EMT-RT 4.

The RTS developer shall clearly document models from the RTS library for the system integrator to check that the models to be used fit with EMT modelling standards and with the scenarios need.

[7] The modelling of the magnetic core saturation and hysteresis can vary from one tool to another, and in particular between offline and real-time, influencing the results.

4.4.3 Possible interfaces

EMT-RT 5.

As a minimum, the simulator shall be capable of handling the following interfaces:

- Hardwired inputs/outputs signals (up to +/- 10 V for analog signals, and from 5V up to 24V for binary/digital signals)
- IEC 61850 interface for sampled values, GOOSE and MMS
- TCP/UDP
- DNP3
- Modbus
- IEC 60870-5-104
- IEEE C37.118
- Aurora protocol, with a speed up to 2 Gbps at least.
- EtherCAT Slave

EMT-RT 6.

In addition to the interfaces with the vendor's control, protection and communication system, it shall be possible to configure the RTS to send a coordinated trigger signal (binary output configured as a pulse) to all the vendors' transient fault recorders, using the interface defined by each vendor.

5. Common requirements

5.1 Standard modeling

LAB-COM 1.

For one given component, several models can be required depending on the studies and the phenomena to be observed.

It is the responsibility of the system integrator to select the appropriate model for each test.

LAB-COM 2.

For each study, the system integrator shall document which model is used and its limitation, to ensure that no conclusion is drawn outside the model's validity.

5.2 Automatic testing possibility

EMT-COM 1.

To perform a high number of simulations, the EMT tool shall provide a solution for the system integrator to execute automatic testing.

The solution shall enable performing simulations autonomously by changing entry parameters on its own.

Example

For example, this can be achieved:

- With a toolbox included in the EMT software
- With an additional piece of software, compatible with the EMT software
- Via scripts

Information

For real-time simulations, it is worth pointing out that the capability of the system integrator to execute automatic testing is also dependent on the capability of each vendor's control and protection system to manage automatic actions. It can:

- Limit the possibilities of performing automatic testing. For example, with HIL, a manual action in the vendor's system can be necessary to reset it after a trip
- Increase the possibilities of performing automatic testing. For example, a tool to automize tests can be developed on the DC Grid Controller

5.3 Automatic performance check and results processing

LAB-COM 3.

The system integrator shall provide a solution for an automatic performance check of the simulations' results. Its purpose is to select the tests where the requirements are not fulfilled or which require a human analysis.

This automatic performance check shall detect for example:

- Unexpected trip
- Unexpected trigger of a specific mode of operation
- Oscillations
- Excessive reaction time or settling time
- Overshoot outside the tolerance
- Steady-state outside the tolerance
- Reverse power flow

LAB-COM 4.

To support this automatic performance check, the system integrator shall provide a solution to automatize as much as possible the concatenation and processing of multiples files coming from different systems (e.g. from each TFR).

Information

Currently, no vendor's requirement is defined in [3] to describe the way to collect all system data for the following analyses.

Consequently, if a specific solution to collect data is desired by the system integrator (for instance, through a VLAN), this shall be discussed with the vendors, to consider cybersecurity risks as well as any operational or technical constraints.

LAB-COM 5.

The system integrator shall have a solution to automatize as much as possible the preparation of the reports associated to the tests.

5.4 Traceability

LAB-COM 6.

The system integrator shall put in place the appropriate methods and solutions to:

- Track precisely the tests list. One test is defined as one unique set of parameters, settings, characteristic of the triggered event, etc. Every test shall have an unique identification number. All the information to be able to repeat exactly the same test without ambiguity shall be given.
- Track precisely the results: which result is associated to which test, and which versions of the simulation tool and of the models have been used for the tests. The results shall be saved in a format adapted to the analysis to be performed.
- Save a copy of all the versions of all models, scripts, etc. used for the tests and for the analysis, to be able to re-perform any test if requested.

5.5 Confidentiality / Accessibility

LAB-COM 7.

The system integrator shall put in place the relevant organization to ensure that:

- The whole data provided at the beginning of the project is given back at the end of it.
- During the project, this provided data is only shared according to the legal framework (and eventual Non-Disclosure Agreement), especially the one protected by Intellectual Property. To ensure this, the data must not be stored on a shared folder which can be accessed by unauthorized people as access must be limited to the persons involved in the project and approved by the vendors.

Abbreviations and Acronyms

	Text
AC	Alternating Current
CIM	Common Information Model
DC	Direct Current
DLL	Dynamic Link Library
EMT	ElectroMagnetic Transients
FACTS	Flexible Alternating Current Transmission Systems
HIL	Hardware-in-the-Loop
HMI	Human Machine Interface
HVDC	High Voltage Direct Current
IBR	Inverter-Based Resource
IO	Input Output
OWF	Offshore Wind Farm
RTS	Real-time Simulator
SIL	Software-in-the-Loop
TFR	Transient Fault Recorder
VLAN	Virtual Local Area Network

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[4] IEC, «IEC Standard 61970 Energy Management system application program interface (EMS-API) - Part 302 : Common Information Model (CIM) dynamics,» 2024.

[5] IEC, «IEC Standard 61970 Energy Management system application program interface (EMS-APi) - Part 457: Dynamics profile,» 2024.

[6] InterOPERA T4.1 group, «Multi-Party Cooperation Framework,» 2024.

Offline EMT Modelling References

Here is a non-exhaustive list of references for offline EMT modelling. The purpose of this list is to provide insight regarding typical phenomena to be modelled and some modelling method examples, without being limitative.

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